Effect of baryon-antibaryon annihilation on the strangeness enhancement (baryon sector)

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Outline

Introduction

Phases in nuclear matter.
Heavy-ion Collisions and Quark Gluon Plasma (QGP).

Probes of QGP

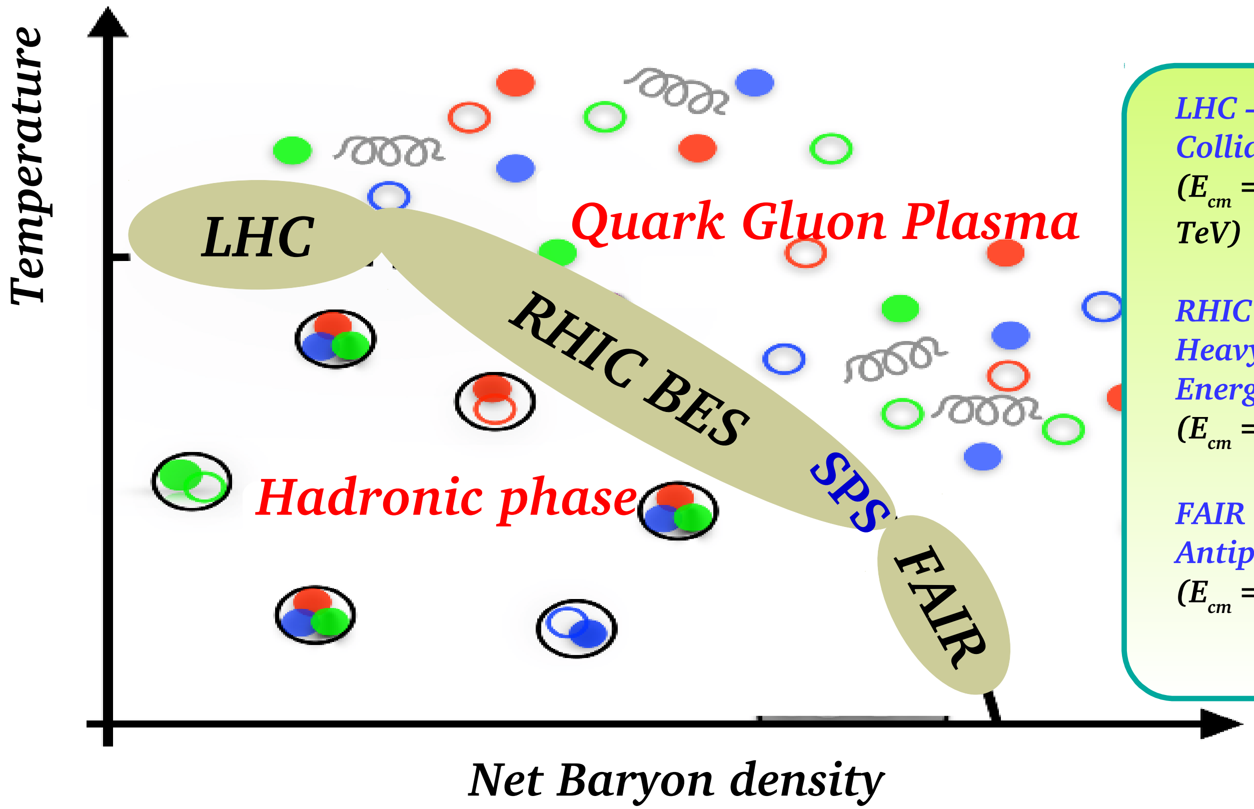
Strangeness enhancement
Measures of strangeness enhancement.

Strangeness production in hadronic models @ CERN-SPS energy
Emphasis on the anti-lambda to anti-proton ratio ($\bar{\Lambda}/\bar{p}$).
Effects of final state interactions (baryon-antibaryon annihilation) and kinematic selections on $\bar{\Lambda}/\bar{p}$.

Summary

Exploring Phase diagram of nuclear matter

- *Mainly two phases of nuclear matter : Hadronic and Quark Gluon Plasma (QGP).*
- *Under extreme conditions of temperature or pressure normal nuclear matter (hadronic phase) is likely to undergo a deconfinement phase transition to a quark-gluon phase.*
- *QCD suggests such a phase transition will occur at an energy density > 5-6 times the normal nuclear density (0.14 GeV/fm^3)~ 1 GeV/fm^3*



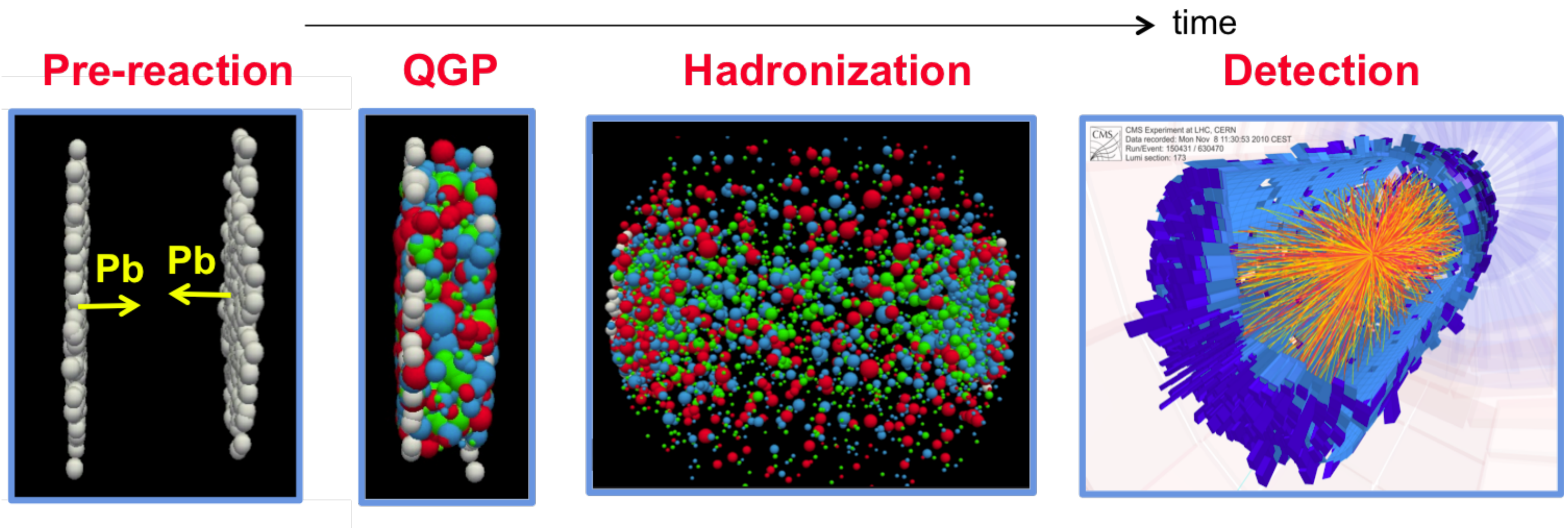
LHC – Large Hadron Collider
(E_{cm} = 2.76TeV – 5.02 TeV)

RHIC BES – Relativistic Heavy Ion Collider Beam Energy Scan
(E_{cm} = 7.7 GeV – 200 GeV)

FAIR – Facility for Antiproton & Ion Research
(E_{cm} = 3 GeV – 9 GeV)

- *Beam Energy Scan program at RHIC @BNL & CERN SPS were launched to probe this new phase of matter with quarks and gluons as relevant dof and characterize it's properties.*
- *Considerable evidence has now been obtained in favour of the deconfinement phase transition and the medium produced is further characterized as an (nearly) equilibrated partonic system- the Quark Gluon Plasma (QGP).*

QGP in the Laboratory



Signatures of QGP

There is no unique signal that will identify QGP. Different signatures are used to search for QGP.

- *J/Ψ suppression*
- *Strangeness enhancement*
- *Jet quenching*
- *Dilepton production*

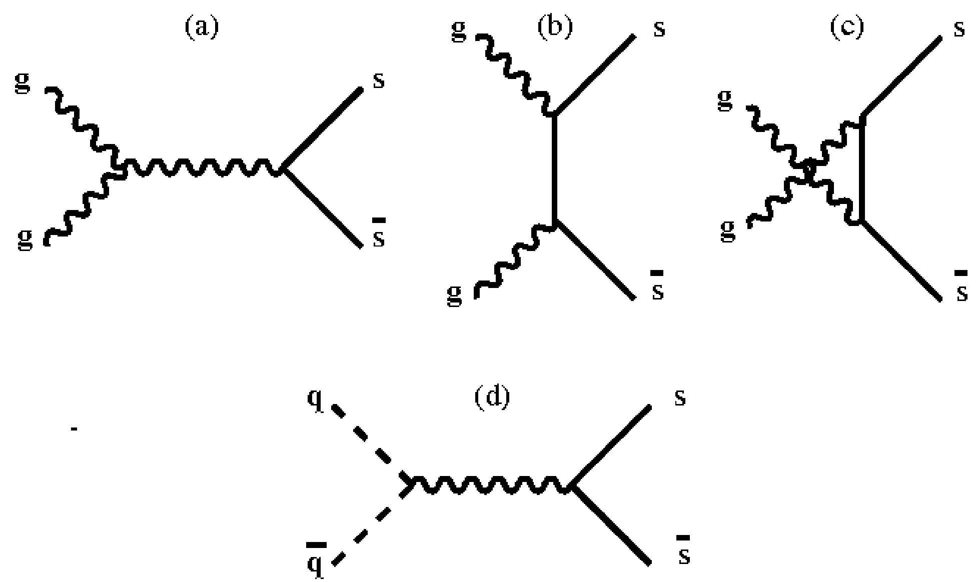
Strangeness production

There is no initial valence strange quark, it produces from the reactions only.

Partonic channel

$g+g \rightarrow s\bar{s}$

$q+\bar{q} \rightarrow s\bar{s}$



Hadronic channel

$N + N \rightarrow N + K + \Lambda$,

$pn \rightarrow \Lambda K^{+}$, $nn \rightarrow \Lambda K^{0}$

$\pi^{+}n \rightarrow \Lambda K^{+}$

Why do we expect strangeness enhancement at low energy?
(Fermi Energy and Pauli Blocking)

- *Because of higher abundance light quarks (u,d) in the medium they fill up the available low energy levels upto the fermi energy.Thus to produce a $u\bar{u}$ pair , required energy = fermi energy + $2m_u$*
- *Thus it is energetically favourable to produce ssbar pairs that require a threshold energy just double the mass of strange quark only.*

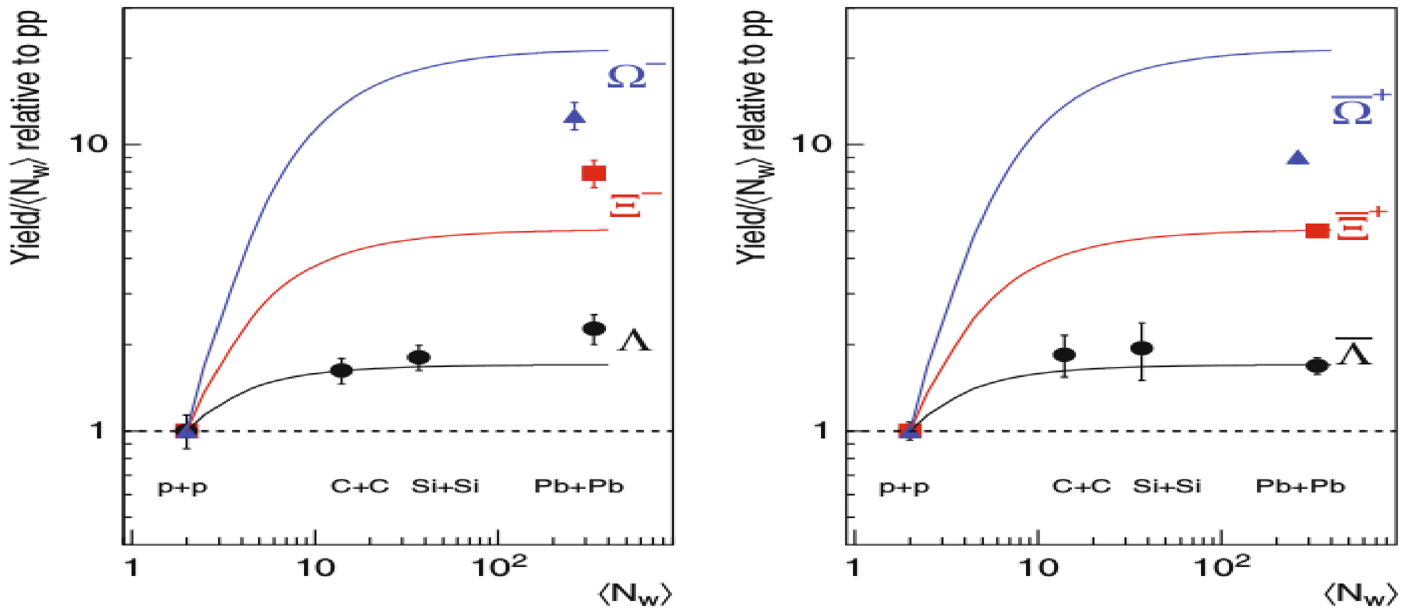
Strangeness Enhancement as a probe of deconfinement

- *J. Rafelski and B. Müller first predicted Strangeness enhancement as a signature of deconfinement.*

- *Large relative enhancement in strange hadrons production relative to pp interaction was reported at SPS energies.*

- *Enhancement factor (relative to pp)* $$E = \frac{2}{\langle N_{part} \rangle} \left[\left. \frac{dN(Pb+Pb)}{dy} \right|_{y=0} \Big/ \left. \frac{dN(p+p)}{dy} \right|_{y=0} \right]$$

- *Enhancement were further seen to exhibit an ordering, based on the net-strangeness content*



SPS- NA49 Data, energy =17.3 GeV

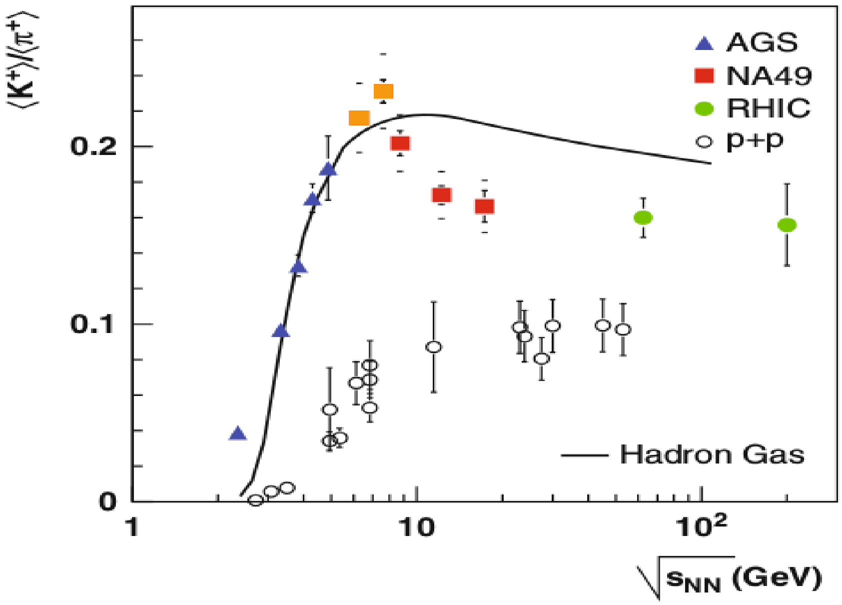
Strangeness Enhancement as a probe of deconfinement

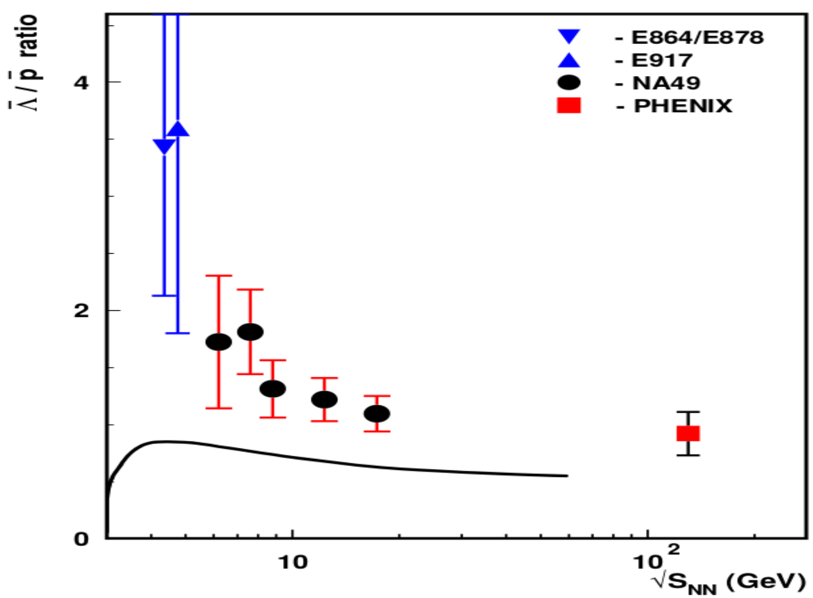
- *Interesting structures were observed in the strange-to-non-strange particle ratios.*

- *Non-monotonic variation of* ***k/π*** *as a function of collision energy was observed.*

- *Similar behaviour was also observed in the baryon sector($\bar{\Lambda}/\bar{p}$), although with large uncertainty.*

- *Such non-monotonic variation is often attributed to the onset of deconfinement.*





Motivation of this work

- *To understand the contributions of hadronic and partonic sources to the measures of strangeness enhancement with focus on the anti-lamda to anti-proton ratio ($\bar{\Lambda}/\bar{p}$).*

- *Since anti-particles comprise of quarks produced in the reactions only, they are regarded as a cleaner channel to probe strangeness enhancement than the usual k/π.*

- *Final yields of $\bar{\Lambda}$ & $\bar{p}$ are however highly sensitive to hadronic interactions at later stages of the collisions mainly from the baryon-anti baryon annihilation.*

- *In a baryon rich environment (low to intermediate SPS energies) such annihilation processes have significant effect on the final yields . So depending on the different annihilation cross-section of $\bar{p}$ and $\bar{\Lambda}$, this ratio ($\bar{\Lambda}/\bar{p}$) can be enhanced.*

- *This study further aims to address whether the enhancement in the ratio ($\bar{\Lambda}/\bar{p}$) can be explained from the consequence of hadronic interactions alone ?*

Details of model simulation

System : Au+Au/Pb+Pb

Energy : 4.7 GeV(Au+Au), 6.27 GeV,7.62 GeV, 8.77 GeV, 12.3 GeV,17.3 GeV

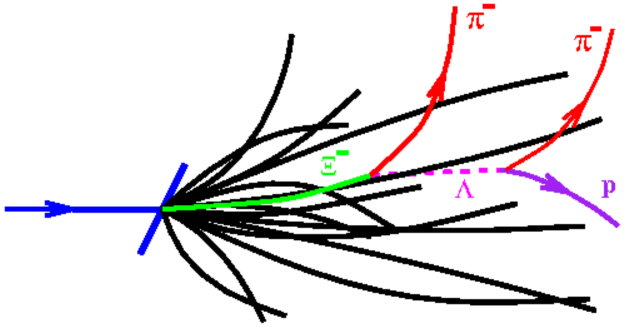
Centrality = 0-7%

Models : UrQMD (Ultra Relativistic Quantum Molecular Dynamics), AMPT (A Multi Phase Transport Model)

Observables : $\bar{\Lambda}, \bar{p}$

In experiment we can not separate $\bar{\Lambda}$ *decayed from* $\bar{\Sigma}$.

As $\bar{\Sigma}$ *lifetime is very small and it decays to* $\bar{\Lambda}$ *immediately. We count* $\bar{\Lambda} + \bar{\Sigma}$.



Description of AMPT and UrQMD

- *We used two (hadronic mode) models to compare with experimental data SPS-NA49, AGS*

***AMPT** --*

- *Initial parton distributions are obtained from HIJING.*
- *These partons then scattered elastially ,which is followed by hadronization.*
- *the final state hadrons are then rescattered untill freezeout.*

***URQMD** –*

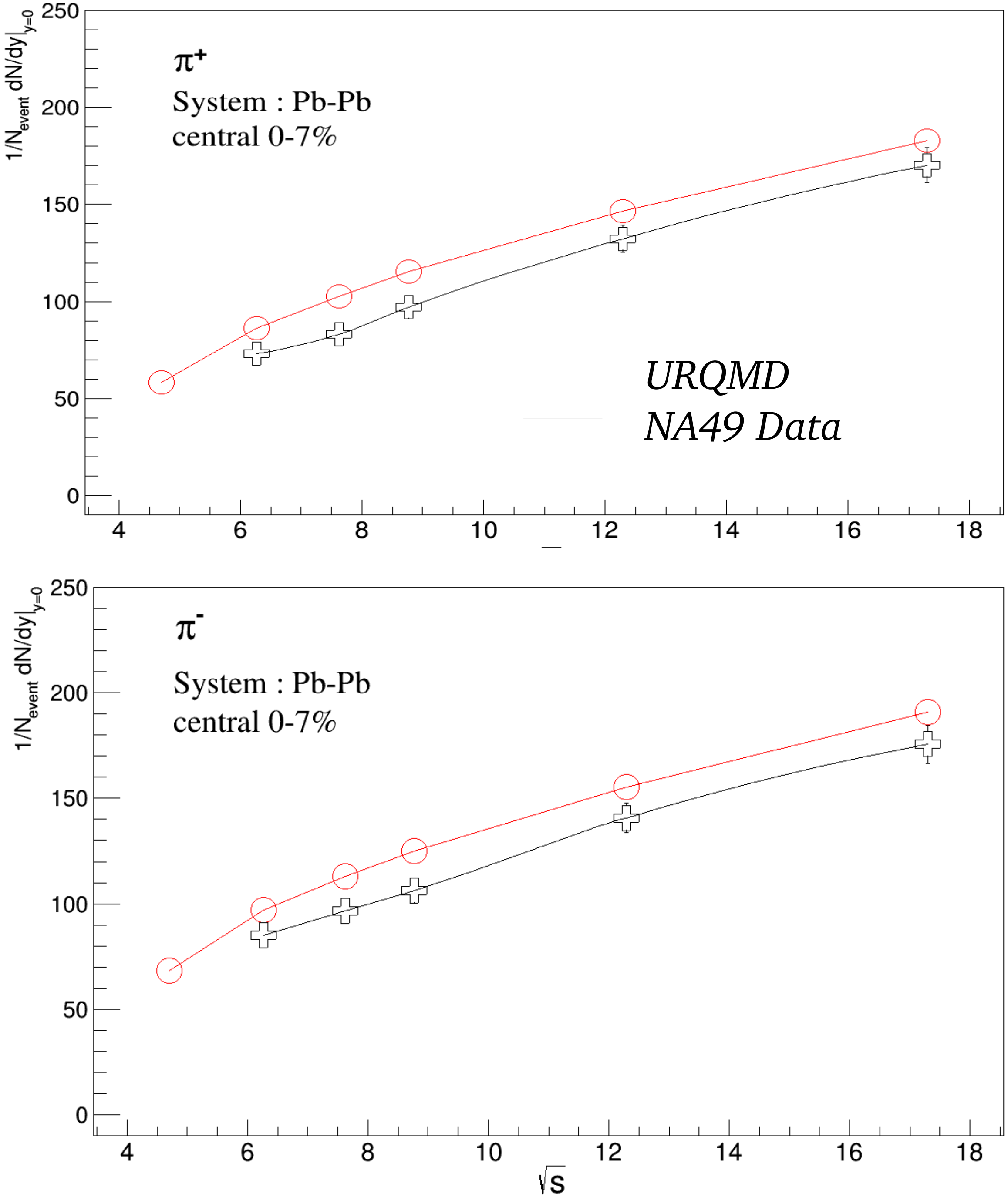
- *The interactions between the incoming nucleons produce high mass resonances or color string.*
- *The high mass resonances then decay and the strings fragment to produce final state particles.*
- *Produced particles are then scattered elastically & inelastically untill freezeout.*

- *Basic difference in these two models lies in the explicit consideration of quark dof in AMPT which is missing in UrQMD.*

Results (UrQMD)-

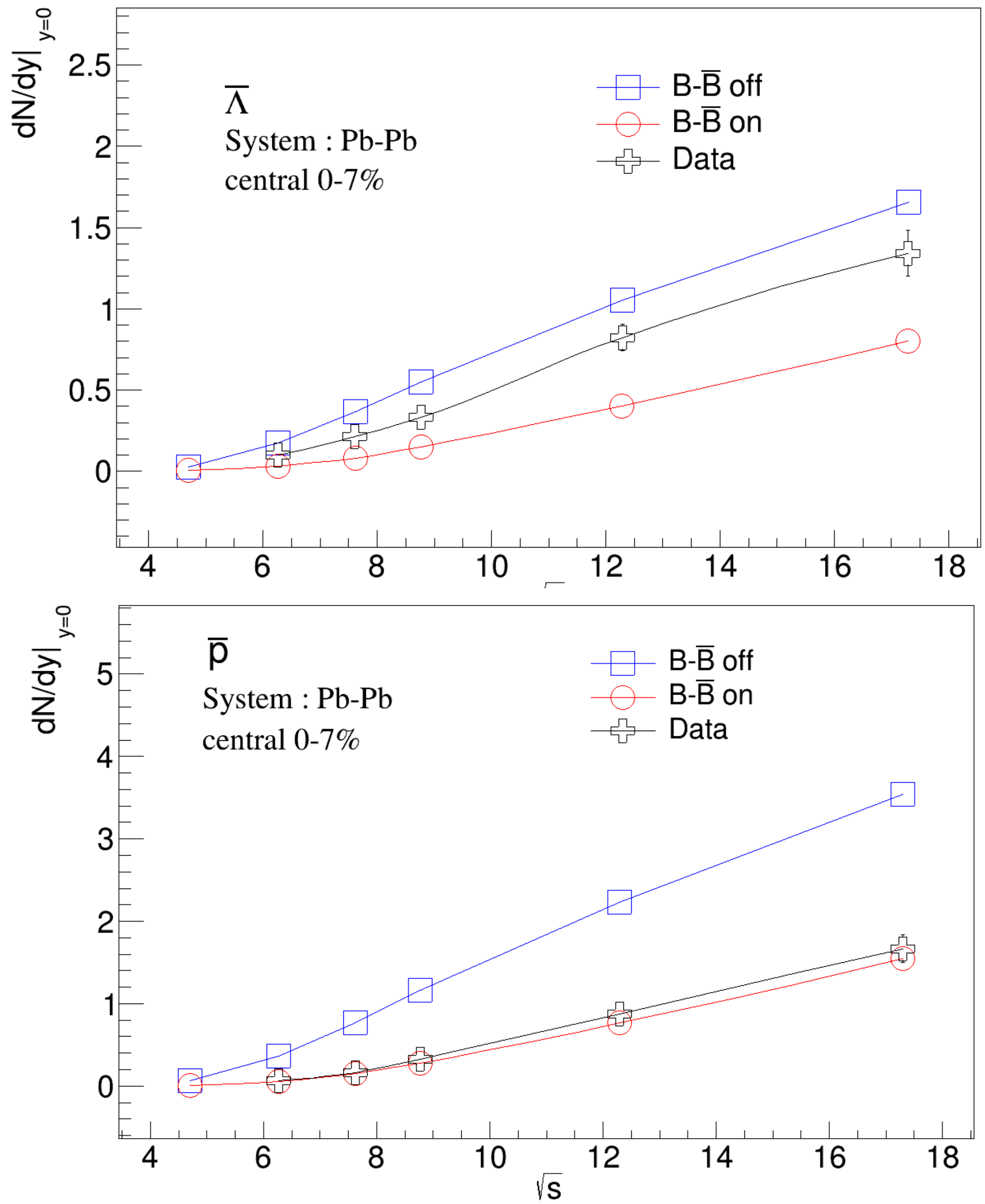
Comparison of mid-rapidity π^+ and π^- yields to NA49 data

- *UrQMD model calculation slightly overestimates the data.*
- *Data to model comparison shows reasonable agreement over the measured energy range.*

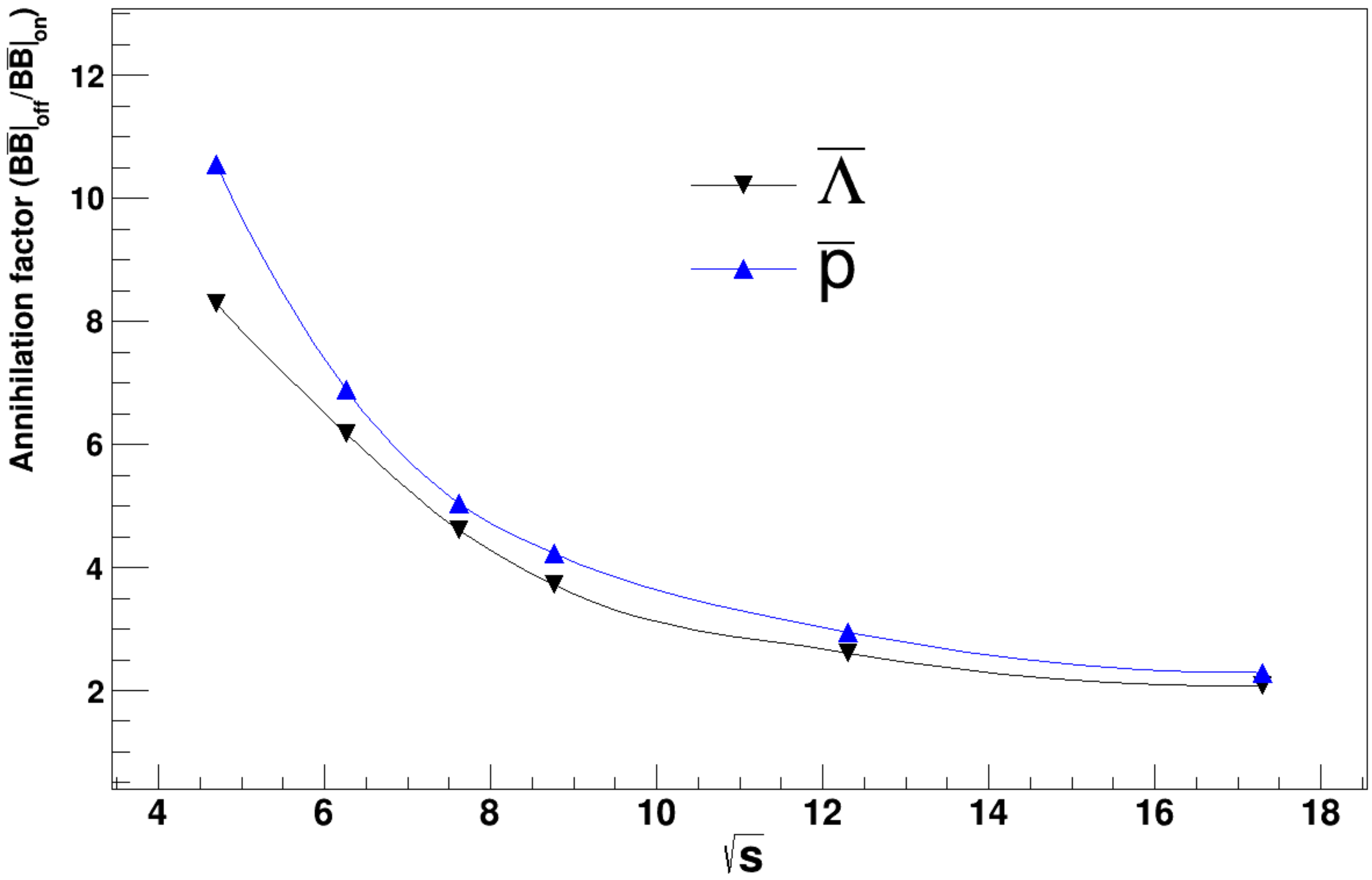


Results : $\bar{\Lambda}$ and $\bar{p}$ yields compared to NA49 data

- *$\bar{\Lambda}$ yield is underestimated & $\bar{p}$ yield matches well.*
- *When B-Bbar annihilation turned-off, UrQMD overestimates yields in data for both species -Implying the significance of annihilation processes.*
- *Annihilation cross sections are parametrized from experimental measurements for p-pbar interactions.*
- *$\bar{\Lambda}$ + **p** annihilation cross section in UrQMD use same parametrization as ppbar but scaled down by ~30%*



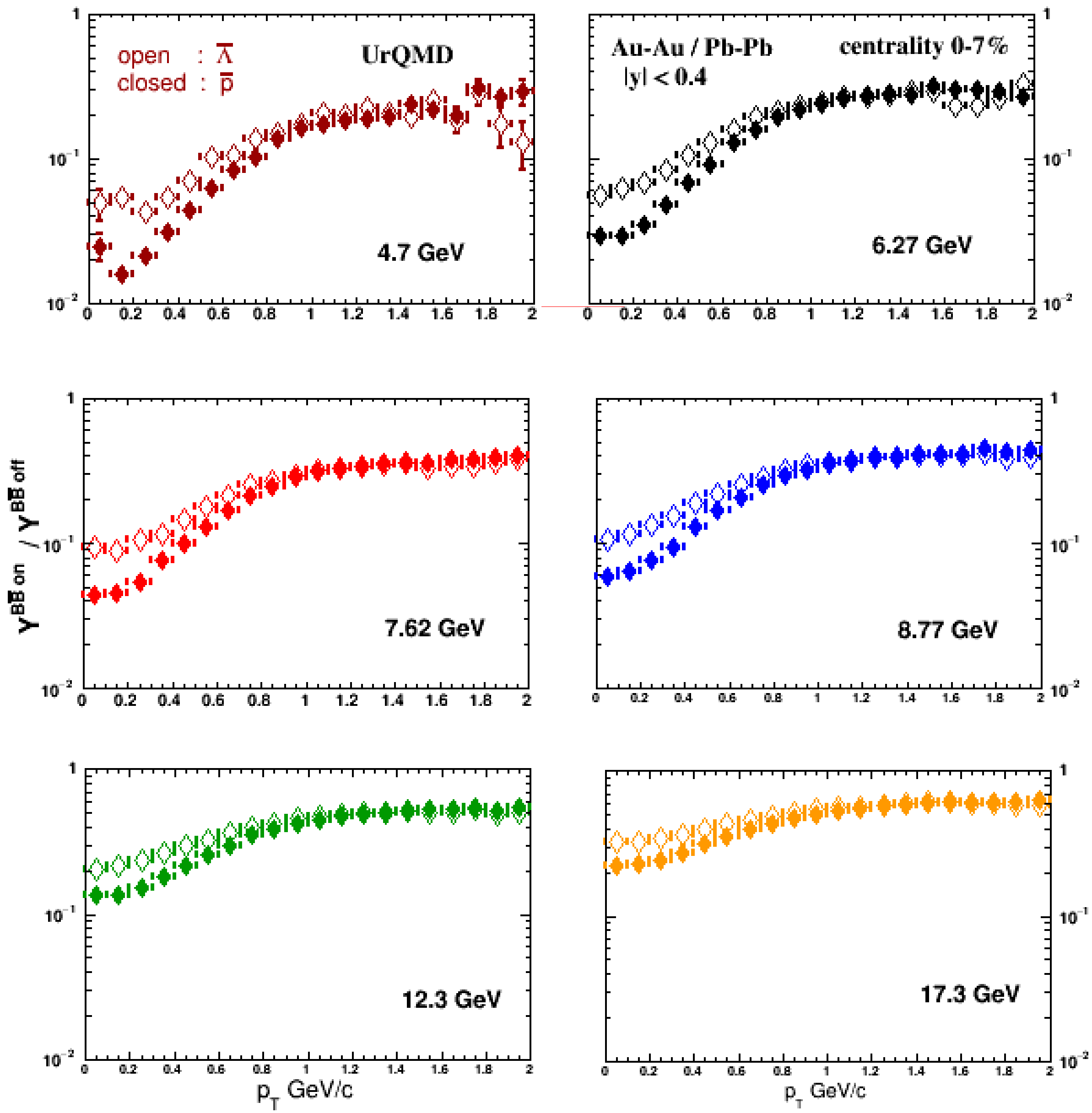
Results – Annihilation effect with beam energy



Annihilation effect is more at lower energy.

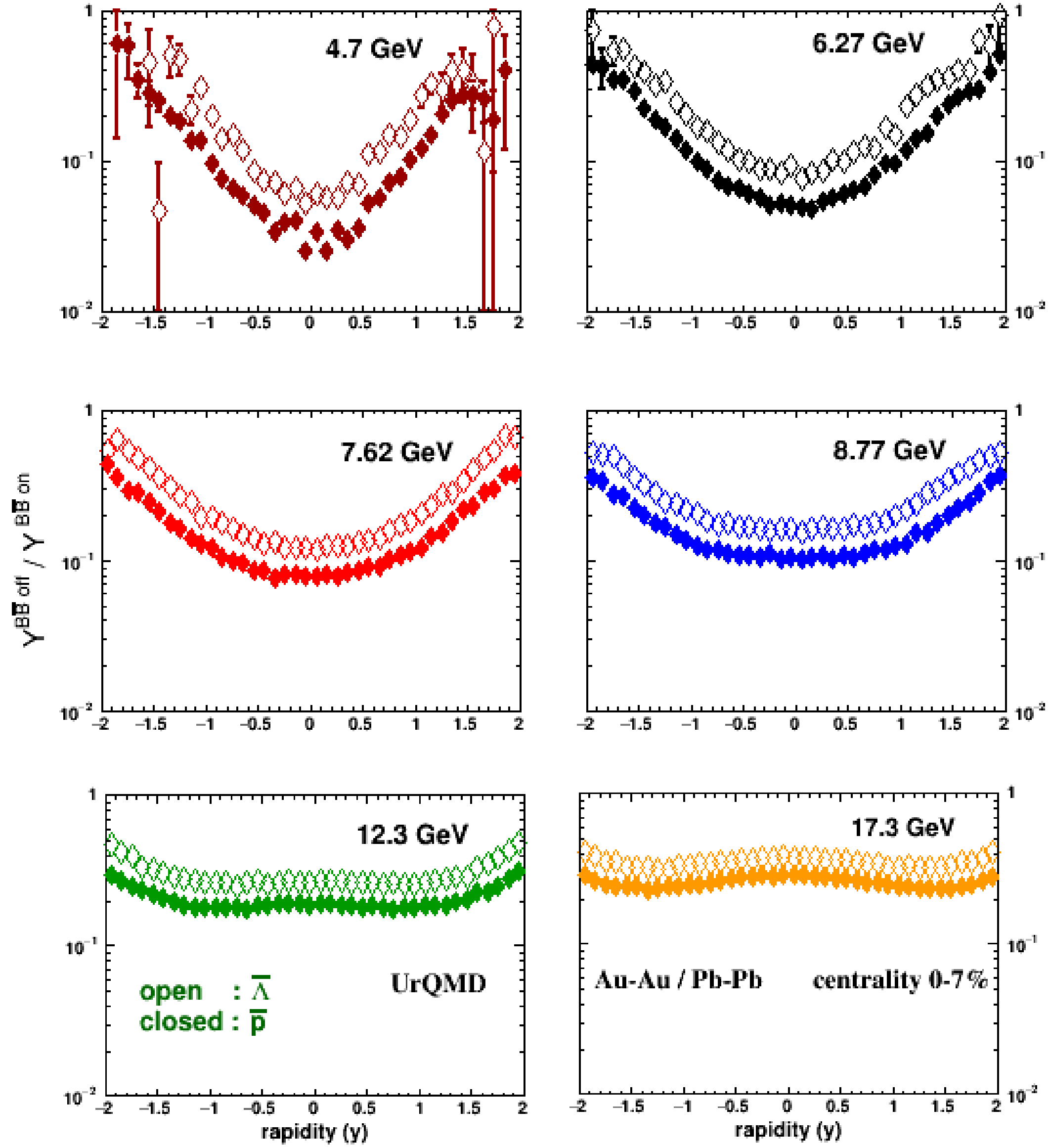
Results: p_T dependence of annihilation effect on Λ and $\bar{p}$ yield

- *Gives an idea on the survival probability of Λ and $\bar{p}$ from the initial state.*
- *Annihilation effect on $\bar{p}$ is higher than Λ low p_T .*
- *Annihilation effect is largest at low p_T and lower energy and gradually decrease with increase in collision energy /p_T*

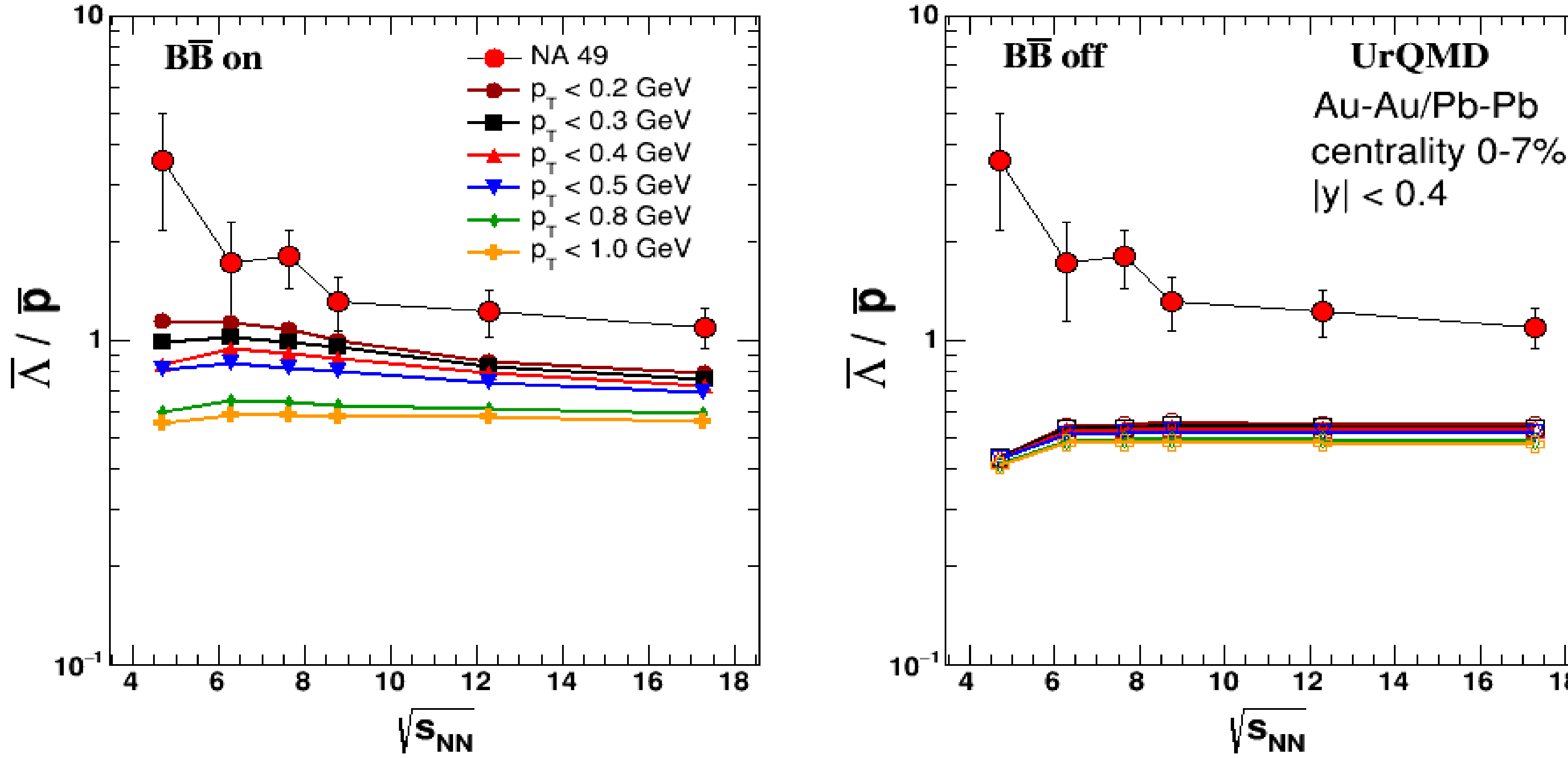


Results: Rapidity dependence of annihilation effect on Λ and $\bar{p}$ yield

- *Annihilation effect is largest at mid-rapidity and shifts to larger rapidity at higher energy*
- *At higher energy net baryon density decreases at mid rapidity but increases towards forward rapidity.*

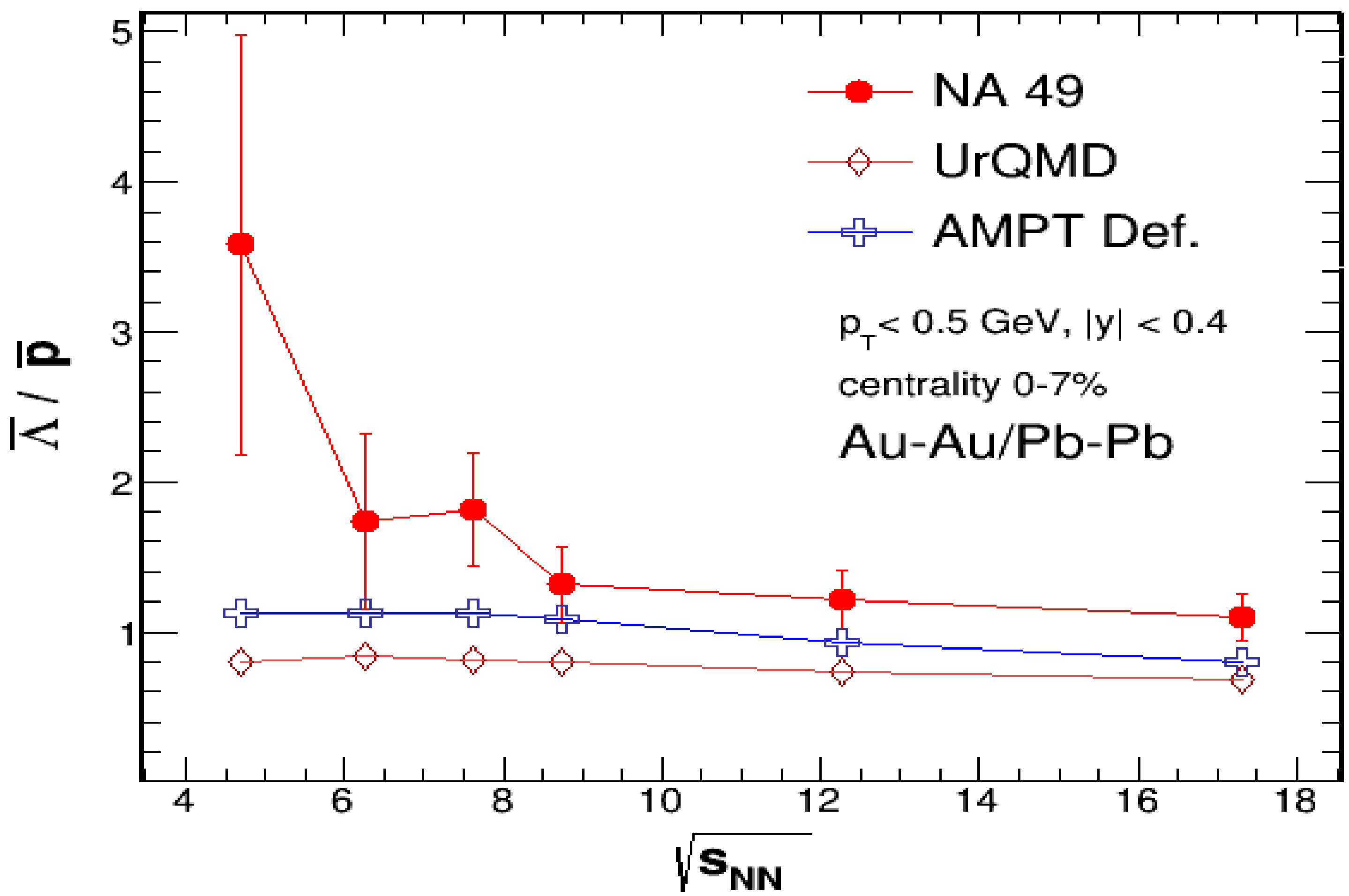


Effect of B-Bbar annihilation on $\bar{\Lambda}/\bar{p}$



- *Ratio increases with lower p_T & decreases with beam energy for Bbar on. Maximum Ratio reaches upto 1.15.*
- *Trend is qualitatively similar to data.*
- *Negligible p_T dependence of ratio in BBbar off with beam energy.*

URQMD & AMPT Model comparison with NA49 data



Ratio calculated from AMPT (hadronic) is higher than UrQMD. However, AMPT does not include annihilation of $\bar{\Lambda}$.

Summary

- *$\bar{\Lambda}/\bar{p}$ has been measured at AGS and SPS as a probe of strangeness enhancement.*

- *A large enhancement in the ratio was reported, consistent to be expectation of strangeness enhancement and, hence the onset of the partonic deconfinement.*

- *However, at large baryon densities, effect of final state interactions due to BBar annihilation could influence the yields significantly.*

- *We studied the effect of BBbar annihilation at on $\bar{\Lambda}/\bar{p}$ based on UrQMD and hadronic version of AMPT.*

- *Model calculation suggests the enhancement in the ratio is sensitive to the annihilation process and also depend on the kinematic selection.*

- *Given the current uncertainty in the data, it can not be firmly concluded whether this enhancement is unique to the increased strangeness production. Nevertheless, the ratio is systematically underestimated in both the hadronic models studied in this case.*

- *In future, we will attempt to paramaterize the BBar annihilation cross section based on the latest available data.*

- *With STAR getting prepared for its second phase of BES and in upcoming CBM experiments, these measurements may help to explore medium properties and particle production dyanmics.*

Thank You

Parametrization of Bbbar annihilation in UrQMD and AMPT

UrQMD and AMPT use some form parametrization of Bbar annihilation cross section, which are nevertheless data-driven.

Both the model assume Bbbar annihilation cross section to be equivalent to ppbar annihilation cross section.

Parametrization for UrQMD is

$$\sigma^{\bar{p}p}_{\mathrm{ann}} = \sigma_0^N \frac{s_0}{s} \left[\frac{\mathrm{A}^2 s_0}{(s-s_0)^2 + \mathrm{A}^2 s_0} + \mathrm{B} \right]$$

AMPT is

$$\sigma^{annih}_{p\bar{p}}(p_{lab}) = 67\, p_{lab}^{-0.7}\ \mathrm{mb}\,,$$

For strange baryons cross sections ... AQM model in UrQMD. However AMPT does not incorporate annihilation of strange-baryons.

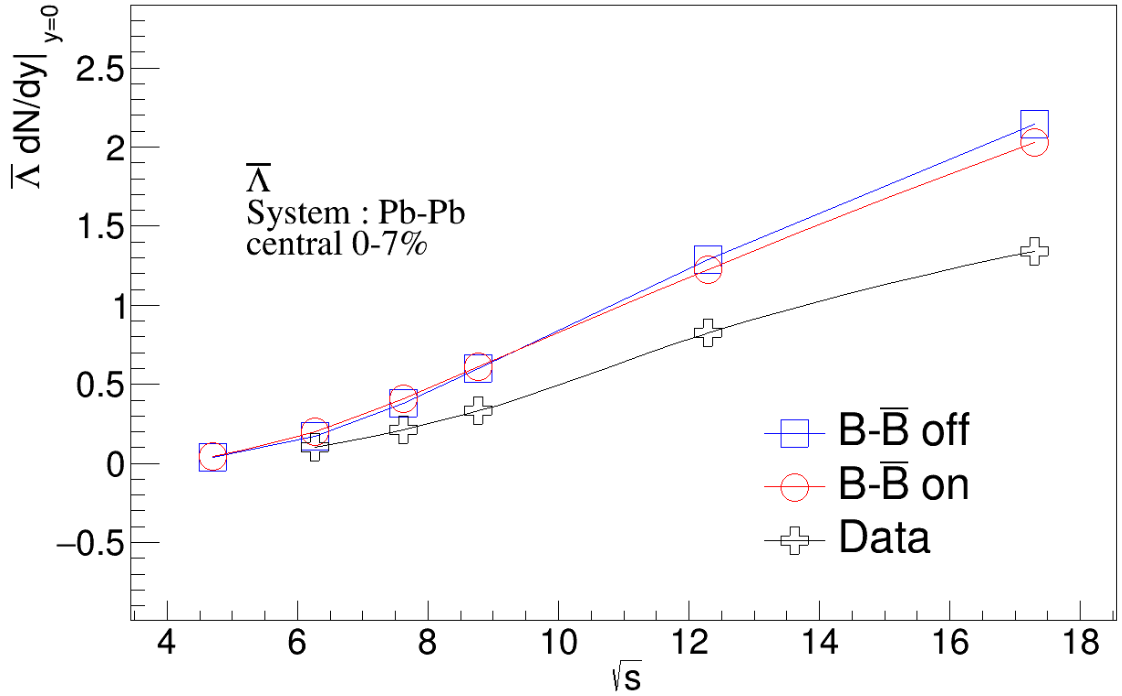
In that sense , UrQMD is more complete.

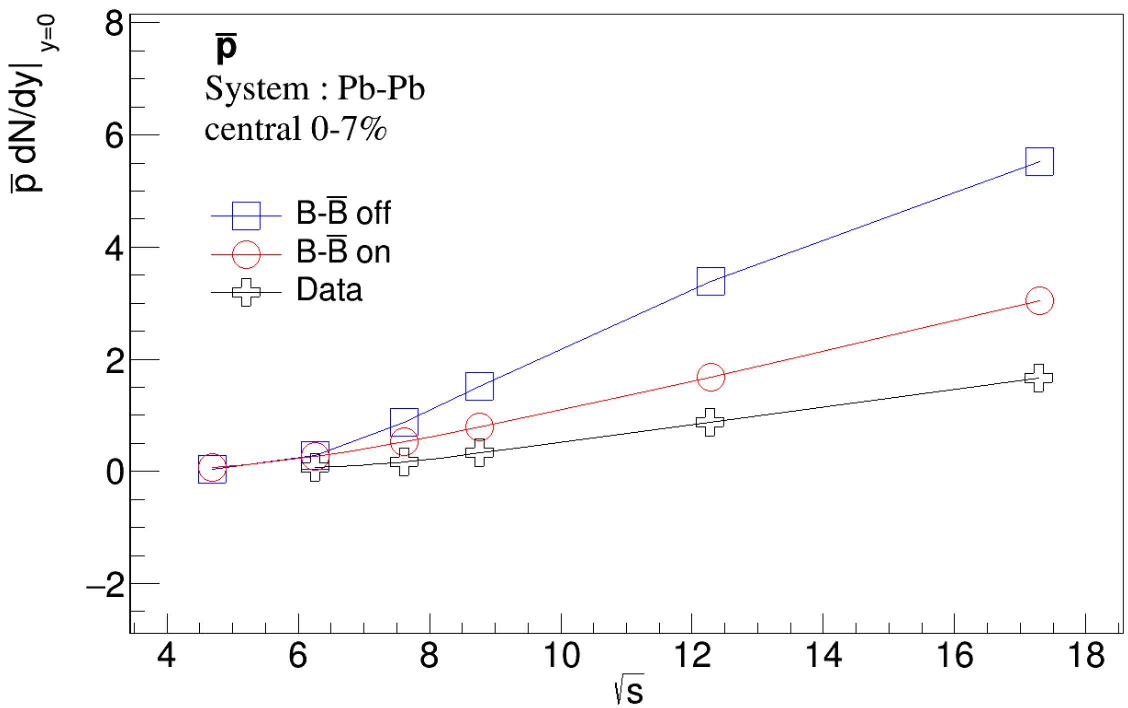
$$f(z) \propto z^{-1}(1-z)^a \exp(-b\, m_\perp^2/z), \qquad (9)$$

with z denoting the light-cone momentum fraction of the produced hadron with respect to that of the fragmenting string. The average squared transverse momentum is

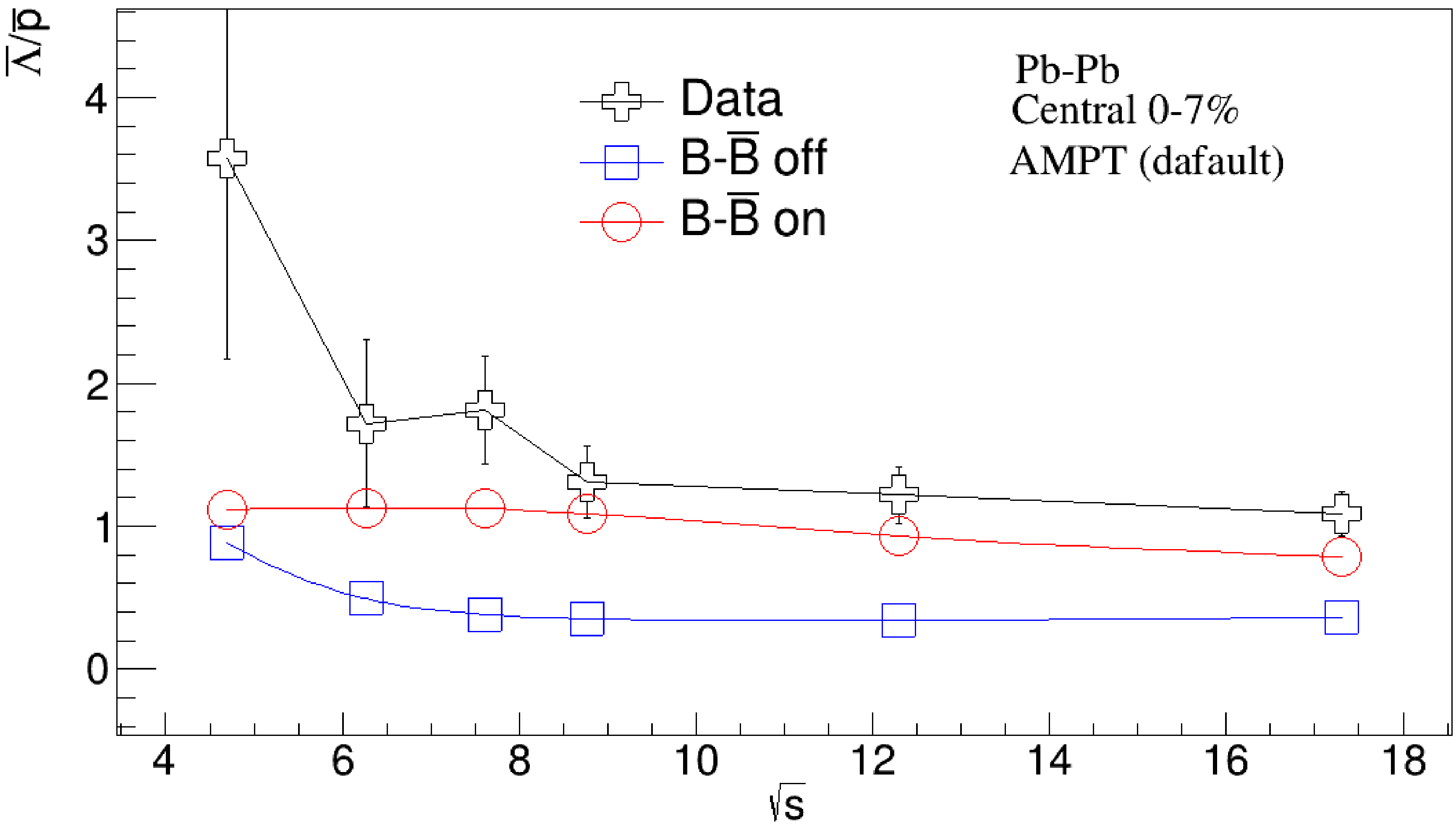
Old plots

AMPT



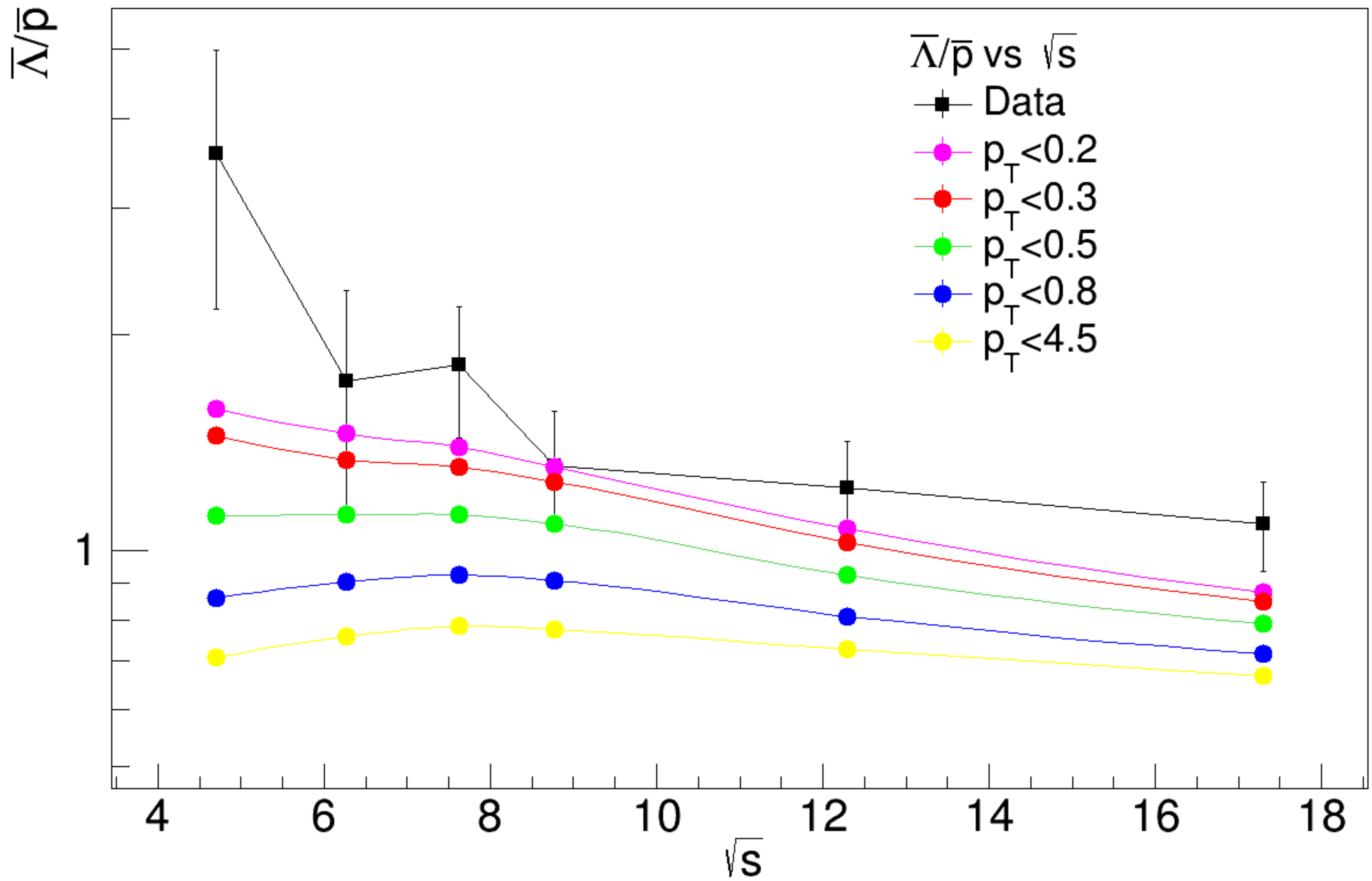


$P_T < 0.5\ GeV/c$



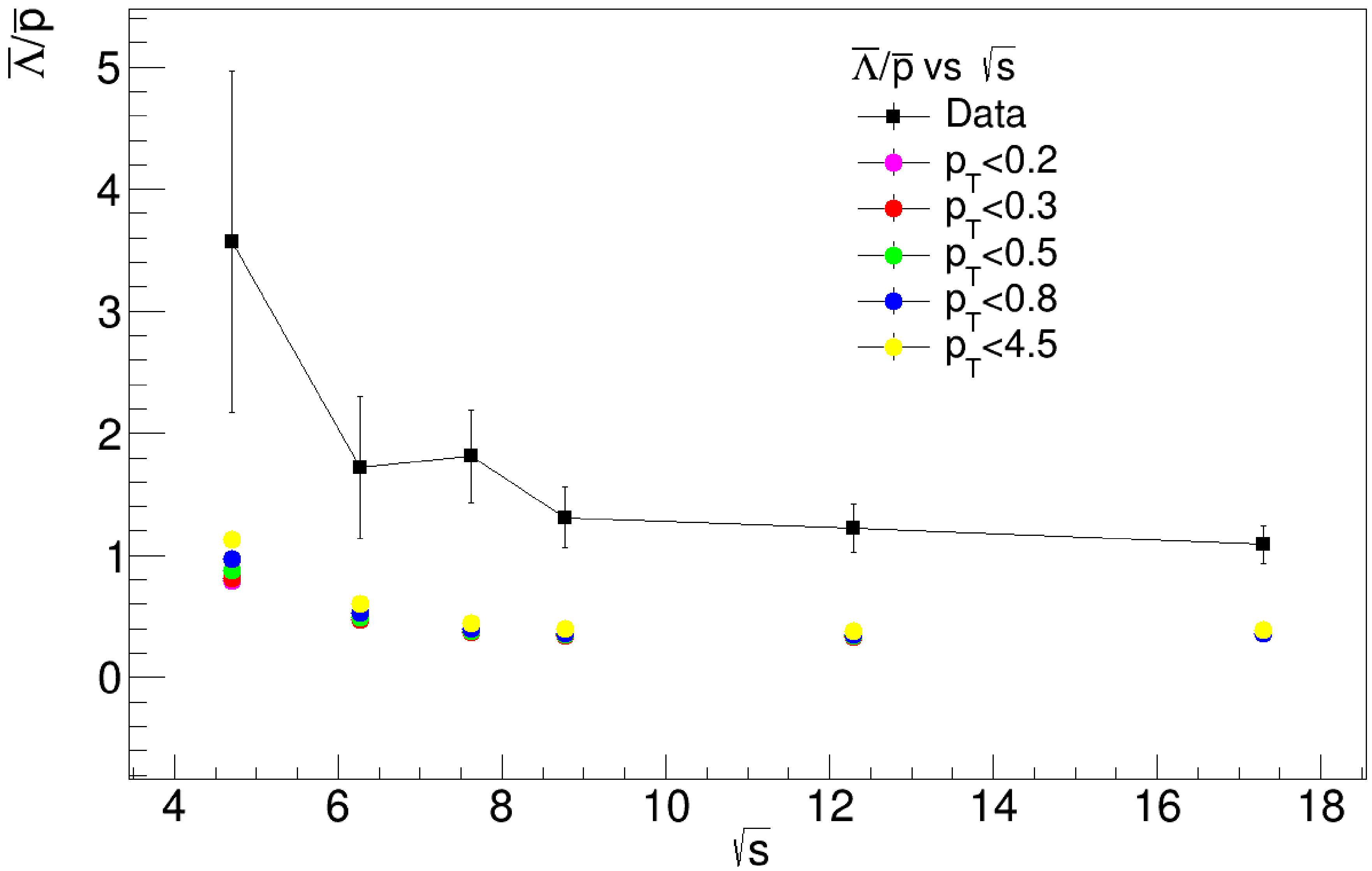
$\overline{\Lambda}/\overline{p}$
4
3
2
1
0
Data
B-$\overline{B}$ off
B-$\overline{B}$ on
Pb-Pb
Central 0-7%
AMPT (dafault)
4
6
8
10
12
14
16
18
$\sqrt{s}$

B-Bbar on



$\overline{\Lambda}/\overline{p}$
$\overline{\Lambda}/\overline{p}$ vs $\sqrt{s}$
Data
p_T<0.2
p_T<0.3
p_T<0.5
p_T<0.8
p_T<4.5
1
4
6
8
10
12
14
16
18
$\sqrt{s}$

B-Bbar off



$\overline{\Lambda}/\overline{p}$ vs $\sqrt{s}$
Data
p_T<0.2
p_T<0.3
p_T<0.5
p_T<0.8
p_T<4.5
$\overline{\Lambda}/\overline{p}$
0
1
2
3
4
5
4
6
8
10
12
14
16
18
$\sqrt{s}$

We used two (hadronic mode) models to compare with experimental data
Difference in AMPT and UrQMD

A Multi Phase Transport Model (AMPT) is a 4-step hybrid MC model
- Obtains initial phase space distributions of strings and partons from HIJING.
- Followed by a partonic scatterings by ZPC, while strings are kept intact.
- At end of the scattering partons are fused to their parent strings.
- Hadronized by Lund string fragmentation approach.
- Produced hadrons are then scattered elastically or in-elastically until freeze-out (time of freeze-out is amodel dependent parameter) via A Relativistic Transport model

Ultra-relativistic Quantum Molecular Dyanmics (UrQMD)
- Describes the different aspects of HI collisions in-terms of interactions of large variety of hadrons and their resonances.
- Initial scatterings of leading Baryons produce high mass resonances and/or colored strings based on a model-dependent threshold.
- The massive resonances further decay while the strings fragment to produce final state particles.
- These final state particles may further scatter until freezeout.

Basic difference in these two models lies in the explicit consideration of partonic dof in AMPT which is missing in UrQMD.